OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET
Complete Only Applicable Items

1. QA: QA

2. ☒ Analysis — Check all that apply		3. ☐ Model — Check all that apply	
Type of Analysis	☐ Engineering ☒ Performance Assessment ☐ Scientific	Type of Model	☐ Conceptual Model ☐ Abstraction Model ☐ Mathematical Model ☐ System Model ☐ Process Model
Intended Use of Analysis	☐ Input to Calculation ☒ Input to another Analysis or Model ☐ Input to Technical Document ☐ Input to other Technical Products	Intended Use of Model	☐ Input to Calculation ☐ Input to another Model or Analysis ☐ Input to Technical Document ☐ Input to other Technical Products
Describe use: The analyses in this report provide input to conceptual model development and analysis for waste package and drip shield degradation.		Describe use:	

4. Title:
FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation

5. Document Identifier (including Rev. No. and Change No., if applicable):
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For TSPA-SR

This document contains citations to draft documents currently in development and all cited reference information will be completed and approved before completion and approval of this document.

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD
Complete Only Applicable Items

2. Analysis or Model Title:

FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation

3. Document Identifier (including Rev. No. and Change No., if applicable):

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4. Revision/Change No.	5. Description of Revision/Change
00	Initial Issue

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1. PURPOSE AND SCOPE

1.1 PURPOSE

As directed by a written development plan (CRWMS M&O 1999a), the primary purpose of this Analyses and Models Report (AMR) is to identify and document the analyses and resolution of the primary features, events, and processes (FEPs) affecting the waste package (WP) and drip shield (DS) degradation process in the repository. Twenty-eight (28) FEPs have been identified as primary FEPs associated with the WP and DS degradation process. This AMR has been prepared to document the FEP inclusion/exclusion process and the screening methodology used in the processes.

1.2 SCOPE

The scope of this AMR is to identify the treatment of the primary FEPs affecting WP and DS degradation. The FEPs that are deemed potentially important to repository performance are evaluated, either as components for the total system performance assessment (TSPA) or as separate analysis in the Analyses and Models Report. The scope for this activity involves two tasks, namely:

Task 1: Identify which FEPs are to be considered explicitly in the TSPA (called included FEP's) and in which AMRs these FEPs are addressed,

Task 2: Identify FEPs not to be included in the TSPA (called excluded FEPs) and provide justification for why these FEPs do not need to be a part of the TSPA model.

The analyses documented in this AMR are for the Enhanced Design Alternative II (EDA II) design (CRWMS M&O 1999b). In this design, a drip shield is placed over the waste package with backfill emplaced over the drip shield (see Design Constraint 2.2.1.1.9 of CRWMS M&O 1999b). The current FEPs list contains 1786 entries. The FEPs have been classified as primary and secondary FEPs and have been assigned to associated Process Model Reports (PMRs). The assignments were based on the nature of the FEPs so that the analysis and resolution for screening decisions reside with the subject-matter experts in the relevant disciplines. This AMR addresses the screening decisions associated with the FEPs for the Waste Package Degradation PMR group. The current FEPs analysis results in this AMR are not applicable to a no-backfill design.

1.3 OVERVIEW OF FEPs ANALYSIS AND DEVELOPMENT

The overall FEPs identification and selection processes are summarized as follows. The initial set of FEPs has been created for the Yucca Mountain Project (YMP) TSPA by combining lists of FEPs identified as relevant to the YMP. This list consists of 1261 FEP entries from the Nuclear Energy Agency working group, 292 FEPs from YMP literature and site studies, and 82 FEPs identified during YMP project staff workshops. These FEPs are organized under 151 categories, based on Nuclear Energy Agency category headings, resulting in a total of 1786 entries in the YMP FEP list. The resulting 1786 entries were broken down into 310 primary FEPs, with the secondary FEPs grouped under the primary FEPs. Those 310 primary FEPs were assigned to the different PMRs (see additional discussion below). The FEPs have been identified by a variety of methods, including expert judgement, informal elicitation, event tree analysis, stakeholder review, and regulatory stipulation. All potentially relevant FEPs have been included, regardless of origin. This approach has led to considerable redundancy in the FEP list, because the same FEPs are frequently identified by multiple sources, but it also ensures that a comprehensive review of narrowly defined FEPs will be performed.

Each FEP has been identified as either a primary or secondary FEP. Primary FEPs are those FEPs for which detailed screening arguments are developed. The classification and description of primary FEPs strives to capture the essence of all the secondary FEPs that map to the primary. Secondary FEPs are either FEPs that are completely redundant or that can be aggregated into a single primary FEP. The primary FEPs have been assigned to associated Process Model Reports (PMRs). The assignments were based on the nature of the FEPs so that the analysis and resolution for screening decisions reside with the subject-matter experts in the relevant disciplines. The resolution of other than system-level FEPs are documented in Analysis and Model Reports (AMRs) prepared by the responsible PMR groups. This section summarizes the screening decisions associated with the FEPs that are relevant to the waste package and drip shield PMR group.

Of the original list of FEPs, twenty-eight (28) have been identified as primary FEPs in relationship to waste package and drip shield degradation. The secondary FEPs assigned to waste package and drip shield degradation have been examined in detail and found to be addressed fully by the analyses applied to the primary FEPs. The approach used for these analyses is a combination of qualitative and quantitative screening of the primary FEPs. The analyses are based on the criteria provided by the Nuclear Regulatory Commission in proposed 10 CFR Part 63 (64 FR 8640), as per direction given by Dyer (Dyer 1999), and by the U.S. Environmental Protection Agency in proposed 40 CFR Part 197 (64 FR 46976) to determine whether or not each FEP should be included in the TSPA. For FEPs that are excluded from the TSPA based on the Nuclear Regulatory Commission or U.S. Environmental Protection Agency criteria, the screening argument includes a summary of the basis and results that indicate either low probability or low consequence. As appropriate, screening arguments cite work done outside this activity, such as in other AMRs. For FEPs that are included in the TSPA, the TSPA disposition includes a reference to the AMR that describes how the FEP has been incorporated in the process models or the TSPA abstraction models.

2. QUALITY ASSURANCE

The analyses were prepared in accordance with the Civilian Radioactive Waste Management system (CRWMS) Management and Operating Contractor (M&O) Quality Assurance (QA) program (DOE 2000). The information provided in the document is to be indirectly used in the evaluation of the Monitored Geologic Repository waste package and engineered barrier segment. The Performance Assessment Operations (PAO) responsible manager has evaluated the technical document development activity in accordance with QAP-2-0, *Conduct of Activities*. The QAP-2-0 activity evaluation (CRWMS M&O 1999c) has determined that the preparation and review of this technical document is subject to Quality Assurance requirements. In accordance with AP-2.13Q, *Technical Product Development Plan*, a work plan was developed, issued, and utilized in the preparation of this document. The documentation of this analysis is in accordance with the guidance given in AP-3.1Q, *Conduct of Performance Assessment*, and the directions found in

AP-3.10Q, *Analyses and Models*. There is no determination of importance evaluation developed in accordance with Nevada Line Procedure, NLP-2-0, since the document does not involve any field activity.

3. COMPUTER SOFTWARE AND MODEL USAGE

No computational software or models were used in the development of the analyses and modeling activities described in this AMR. The analyses and arguments presented herein are based on regulatory requirements, the results from other AMRs, or documented technical literature. This AMR utilizes a Microsoft Access database (see Section 4.1). This database was setup to identify FEPs that are relevant to the performance of the Yucca Mountain site.

4. INPUTS

4.1 DATA AND PARAMETERS

The technical information used in this AMR as input has been obtained, where possible, from controlled source documents and references using the appropriate document identifiers or records system accession numbers.

The input for this study consists of FEPs in the database which are deemed primary FEPs with respect to their effects on the waste package (WP) and drip shield (DS) degradation process in the repository. The AP-2.13Q development plan is titled “Analysis to Develop a Comprehensive Database of Features, Events, and Processes (FEPs) Potentially Relevant to the Long Term Performance of the Proposed Yucca Mountain Repository” (CRWMS M&O 1999d). As stated in the aforementioned development plan, the electronic database contains “a comprehensive list of FEPs potentially relevant to the long-term performance of the repository” and is capable of storing and retrieving information about the treatment of the FEPs in the TSPA. The YMP FEPs database consists of 1786 entries and is filed in the Records Processing Center (RPC) (CRWMS M&O 1999i).

Two sources have been used as sources of “accepted” data regarding metal properties. The first, ASM International 1987, is a handbook of metal properties and contains “accepted data”. The second, Haynes International 1993, contains data provided by a manufacturer and can also be considered “accepted data”.

One preliminary source has been used to resolve issues regarding the “Exclude” status of some of the FEPs analyzed in this AMR. This is an input transmittal titled *Features, Events and Processes Resolution Responses* (CRWMS M&O 2000a). The inputs from this source has been identified with To Be Verified (TBV) status in the Document Input Reference System database (DIRS).

4.2 CRITERIA

Technical screening criteria are provided as per DOE’s interim guidance (Dyer 1999) as identified by the NRC in proposed 10 CFR Part 63 (64 FR 8640) and by the EPA in proposed 40 CFR Part 197 (64 FR 46976).

The proposed NRC regulations specifically allow the exclusion of FEPs from the TSPA if they are of low probability (less than one chance in 10,000 of occurring in 10,000 years) or if occurrence of the FEP can be shown to have no significant effect on expected annual dose.

4.2.1 Low Probability

The probability criterion as stated in the DOE's interim guidance (Dyer 1999) as identified by the NRC in proposed 10 CFR Section 63.114 (d) (64 FR 8640).

> "Consider only events that have at least one chance in 10,000 of occurring over 10,000 years."

The EPA provides essentially the same criterion in proposed 40 CFR Section 197.40(64 FR 46976)

> "The DOE's performance assessments should not include consideration of processes or events that are estimated to have less than one chance in 10,000 of occurring within 10,000 years of disposal."

Because the probability of any specific event depends strongly on how it is defined, the probability criterion can only be applied on an appropriately broad scale. For example, the probability of seismic events should be evaluated over the entire 10,000-year period, rather than being artificially lowered by defining 10,000 different seismic events each occurring in a different year.

4.2.2 Low Consequence

Criteria for low consequence screening arguments as stated in the DOE's interim guidance (Dyer 1999) as identified by the NRC in proposed 10 CFR Section 63.114(e-f) (64 FR 8640)

(e) Provide the technical basis for either inclusion or exclusion of specific features, events, and processes of the geologic setting in the performance assessment. Specific features, events, and processes of the geologic setting must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission.

(f) Provide the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers. Degradation, deterioration, or alteration processes of engineered barriers must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission.

The EPA provides essentially the same criteria in proposed 40 CFR Section 197.40 (64 FR 46976).

> "…with the NRC's approval, the DOE's performance assessment need not evaluate, in detail, the impacts resulting from any processes and events or sequences of processes and events with a higher chance of occurrence if the results of the performance assessment would not be changed significantly."

These criteria allow omitting those FEPs that can be shown to have no significant effect on the expected annual dose. "Significant" is an undefined term in the regulations and the lack of a significant effect must be demonstrated on a case-by-case basis for each FEP. Because the relevant performance measures differ for different FEPs (e.g., effects on performance can be measured in terms of changes in concentrations, flow rates, travel times, and other measures as well as overall expected annual dose), there is no single quantitative test of "significance."

4.3 CODES AND STANDARDS

This AMR was prepared to comply with the DOE interim guidance (Dyer 1999) which directs the use of specified Subparts/Sections of the proposed NRC high-level waste rule, 10 CFR Part 63 (64 FR 8640). Subparts of this proposed rule that are applicable to data include Subpart B, Section 15 (Site Characterization) and Subpart E, Section 114 (Requirements For Performance Assessment), Subpart F (Performance Confirmation Program) and Subpart G (Quality Assurance). The subpart applicable to models is also outlined in Subpart E Section 114.

5. ASSUMPTIONS

There are three assumptions made in screening of the waste package FEPs. These assumptions or combinations thereof are used throughout this report.

1) As directed by regulation (Dyer 1999, Section 114(l)), assume "evolution of the geologic setting consistent with present knowledge of natural processes".

The assumption affects waste package and drip shield FEPs concerned with geologic processes. The assumption implies that existing knowledge of natural processes is sufficient to adequately quantify future states of the system.

2) Assume that the repository will be constructed, operated, and closed according to the regulatory requirements applicable to the construction, operation, and closure period and that deviations from design will be detected and corrected.

This assumption is justified based on the conditions specified in proposed 10 CFR Section 63.32, which pertains to construction authorization and which requires

> "Periodic or special reports regarding:
>
> (1) Progress of construction;

(2) Any data about the site, obtained during construction, that are not within the predicted limits on which the facility design was based;

(3) Any deficiencies, in design and construction, that, if uncorrected, could adversely affect safety at any future time".

In addition, proposed 10 CFR 63 Subpart F requires that a performance confirmation program be instituted. The focus of the program is confirmation of geotechnical and design parameters (Section 63.132), design testing (Section 63.133) and monitoring and testing waste packages (Section 63.134). In addition, under proposed 10 CFR 63 Subpart G, quality assurance requirements are applied to "site characterization, facility and equipment construction, facility operation, performance confirmation, permanent closure, and decontamination and dismantling of surface facilities". The assumption impacts waste package and drip shield FEPs that are affected by events occurring during the construction, operation, or closure period.

3) Assume that the design parameters for the waste package and drip shield can be used to justify an exclude decision.

This assumption is justified based on the conditions specified in proposed 10 CFR 63.32 Subpart G that pertains to quality assurance.

> "Quality assurance includes quality control, which comprises those quality assurance actions related to the physical characteristics of a material, structure, component or system that provide a means to control the quality of the material, structure, component or system to predetermined requirements".

The assumption allows exclusion of FEPs when the design process specifically addresses the issue described by that particular FEP. Note that deviation from a design process despite a set of quality controls is allowed for in the TSPA. One example is the mechanism of "juvenile" failures of the waste package and/or drip shield (CRWMS M&O 2000p).

If a particular FEP meets the requirements of any of these assumptions it will be considered to a have a low probability of occurrence, even though it is not possible, in the current analysis, to assign a quantitative value to the probability.

6. ANALYSES AND MODELS

The FEPs are classified as either primary or secondary. Primary FEPs are those which will require the development and documentation of screening arguments. Secondary FEPs are redundant or are considered a part of another FEP. Of primary concern in this AMR is the addressing and documenting of the screening arguments for the primary FEPs. Of the original list of FEPs, twenty-eight (28) have been identified as primary in relationship to waste package (WP) and drip shield (DS) degradation. The 28 primary FEPs addressed in this AMR are listed in Table 1.

The technical information used in this AMR as input has been obtained, where possible, from controlled source documents and references using the appropriate document identifiers or records system accession numbers. In some cases, the technical information strongly supports an exclude decision for a particular FEP but is not sufficiently rigorous to support the low probability or low consequence criteria (see Section 4.2 for details of these criteria). In these instances the Screening Decision has been labelled "To Be Verified (TBV) pending additional data and/or analysis". The TBV designation will be carried in the FEPs data base until it is resolved.

Table 1. List of Primary FEPs Addressed in this AMR.

FEP NAME	YMP FEP DATABASE NUMBER
Error in waste or backfill emplacement	1.1.03.01.00
Fault movement shears waste container	1.2.02.03.00
Seismic vibration causes container failure	1.2.03.02.00
Magma interacts with waste	1.2.04.04.00
Corrosion of waste containers	2.1.03.01.00
Stress corrosion cracking of waste containers	2.1.03.02.00
Pitting of waste containers	2.1.03.03.00
Hydride cracking of waste containers	2.1.03.04.00
Microbially-mediated corrosion of waste container	2.1.03.05.00
Internal corrosion of waste container	2.1.03.06.00
Mechanical impact of waste container	2.1.03.07.00
Juvenile and early failure of waste containers	2.1.03.08.00
Copper corrosion	2.1.03.09.00
Container healing	2.1.03.10.00
Container form	2.1.03.11.00
Container failure (long term)	2.1.03.12.00
Effects and degradation of drip shield	2.1.06.06.00
Effects of material interfaces	2.1.06.07.00
Rockfall (large block)	2.1.07.01.00
Creeping of metallic materials in the EBS	2.1.07.05.00
Volume increase of corrosion products	2.1.09.03.00
Electrochemical effects in waste and EBS	2.1.09.09.00
Biological activity in waste and EBS	2.1.10.01.00
Differing thermal expansion of repository components	2.1.11.05.00
Thermal sensitization of waste containers increases fragility	2.1.11.06.00
Gas generation (H_2) from metal corrosion	2.1.12.03.00
Radiolysis	2.1.13.01.00
Radiation damage in waste and EBS	2.1.13.02.00

6.1 APPROACH

The approach used for this analysis is a combination of qualitative and quantitative screening of FEPs. The analyses are based on the criteria provided by the NRC in proposed 10 CFR Part 63 (64 FR 8640) and by the EPA in proposed 40 CFR Part 197 (64 FR 46976) to determine whether or not each FEP should be included in the TSPA.

For FEPs that are excluded from the TSPA based on NRC or EPA criteria, the screening argument includes a summary of the basis and results that indicate either low probability or low consequence. As appropriate, screening arguments cite work done outside this activity, such as in other AMRs. If needed, a more detailed discussion is provided in the Analysis/Discussion section.

For FEPs that are included in the TSPA, the TSPA Disposition includes a reference to the AMR that describes how the FEP has been incorporated in the process models or the TSPA abstraction.

In addition to documenting the disposition and the justification for the disposition of the primary FEPs that could affect waste package and drip shield degradation, this report serves an additional purpose. In order to fulfill its oversight role for the Yucca Mountain Project (YMP), the staff of the Nuclear Regulatory Commission (NRC) has developed a process for early resolution of technical issues. The NRC staff issued the Issue Resolution Status Report for Container Life and Source Term Key Technical Issue (CLST KTI) (NRC, 1999), which is considered by the NRC staff one of the technical issues important to post-closure performance of the proposed geologic repository. This AMR shows the correspondence between FEPs that could affect waste package and drip shield degradation processes and technical issues relevant to the CLST KTI. The technical issues that are relevant to the waste package and drip shield degradation are:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers;
Subissue 2: The Effects of Phase Instability and Initial Defects on the Mechanical Failure and Lifetime of the Containers;
Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem

The current design calls for a drip shield overlying the waste container/package and backfill placed over the drip shield (CRWMS M&O 1999b, Design Constraint 2.2.1.1.9). However, in some cases a particular FEP title or description will mention only one or the other of the waste container/package and drip shield. In such instances it is proposed that the FEP title and/or FEP description be modified to help clarify the subject. For these FEPs the original text and the proposed modifications are shown in Table 2. Note that the FEP titles and descriptions are not modified in Section 6.2 to maintain consistency with the current form of the FEPs database.

Table 2. Original and Modified FEP Titles and Descriptions.

Section	FEP Number	Original Text	Modified Text
6.2.3	1.2.03.02.00	Seismic vibration causes container failure	Seismic vibration causes waste container and drip shield failure
		Seismic activity causes repeated vibration of container and/or container-rock wall contact, damaging the container and its contents.	Seismic activity causes repeated vibration of the waste container and drip shield and/or waste container and drip shield-rock wall contact, damaging the drip shield and waste container and its contents.
6.2.5	2.1.03.01.00	Corrosion of Waste Containers	Corrosion of Waste Containers and Drip

Section	FEP Number	Original Text	Modified Text
			Shields
		Corrosion may contribute to waste package failure. Corrosion is most likely to occur at locations where water drips on the waste packages, but other mechanisms should be considered.	Corrosion may contribute to waste package and drip shield failure. Corrosion is most likely to occur at locations where water drips on the waste packages or drip shields, but other mechanisms should be considered.
6.2.6	2.1.03.02.00	Stress Corrosion Cracking of Waste Containers	Stress Corrosion Cracking of Waste Containers and Drip Shields
		Waste packages become wet at specific locations that are stressed. Stress-corrosion cracking ensues. The possibility of stress corrosion cracking under dry conditions or due to thermal stresses should also be addressed as part of this FEP.	Waste packages and drip shields become wet at specific locations that are stressed. Stress-corrosion cracking ensues. The possibility of stress corrosion cracking under dry conditions or due to thermal stresses should also be addressed as part of this FEP.
6.2.7	2.1.03.03.00	Pitting of Waste Containers	Pitting of Waste Containers and Drip Shields
		Localized corrosion in pits leads to failure of the waste package.	Localized corrosion in pits leads to failure of the waste package and drip shield.
6.2.8	2.1.03.04.00	Hydride cracking of waste containers	Hydride cracking of waste containers and drip shields
6.2.9	2.1.03.05.00	Microbially-mediated corrosion of waste container	Microbially-mediated corrosion of waste container and drip shield
6.2.11	2.1.03.07.00	Mechanical impact on waste container	Mechanical impact on waste container and drip shield
		Mechanical impact on the waste container is caused by internal and external forces such as internal gas pressure, forces caused by swelling corrosion products, rock fall, ground motion during seismic events, and possible waste package movement.	Mechanical impact on the waste container and drip shield is caused by internal and external forces such as internal gas pressure, forces caused by swelling corrosion products, rock fall, ground motion during seismic events, and possible waste package movement.
6.2.12	2.1.03.08.00	Juvenile and early failure of waste containers	Juvenile and early failure of waste containers and drip shields
6.2.16	2.1.03.12.00	Container failure (long term)	Waste container and drip shield failure (long term)
6.2.19	2.1.07.01.00	Rockfall (large block)	
		Rockfalls occur large enough to mechanically tear or rupture waste packages.	Rockfalls occur large enough to mechanically tear or rupture waste packages and drip shields.
6.2.25	2.1.11.06.00	Thermal Sensitization of Waste Containers Increases Fragility	Thermal Sensitization of Waste Containers and Drip Shields Increases their Fragility
		Phase changes in waste package materials can result from long-term storage at moderately hot temperatures in the repository. Stress-corrosion cracking, intergranular corrosion, or mechanical degradation may ensue.	Phase changes in waste package and drip shield materials can result from long-term storage at moderately hot temperatures in the repository. Stress-corrosion cracking, intergranular corrosion, or mechanical degradation may ensue.

6.2 PRIMARY FEPS ANALYSES

This AMR addresses the 28 FEPs that have been identified as primary FEPs. These FEPs are best dealt with subject-matter experts in the relevant disciplines. The FEPs discussed in this report are relevant to the waste package and drip shield degradation PMR, however, there may be instances of overlap with other PMRs.

6.2.1 Error in Waste or Backfill Emplacement 1.1.03.01.00

FEP Description: Deviations from the design and/or errors in waste and backfill emplacement could affect long-term performance.

Screening Decision: Exclude

Screening Decision Basis: Low Probability

Screening Argument: This FEP can be excluded under Assumption 2 (Section 5). Assumption 2 states that “assume that the repository will be constructed, operated, and closed according to the regulatory requirements applicable to the construction, operation, and closure period and that deviations from design will be detected and corrected”. Note that proposed 10 CFR Section 63.133 (c) specifically addresses the backfill issue. It states “a backfill test section shall be constructed to test the effectiveness of backfill placement and compaction procedures against design requirements before permanent backfill placement is begun.” This FEP is excluded based on low probability constrained by the design requirements discussed above.

This FEP is also discussed in the EBS FEPs AMR (CRWMS M&O 2000c) and also excluded.

TSPA Disposition: Exclude from the TSPA as described under the Screening Argument.

Relevant AMRs: CRWMS M&O 2000c. *Engineered Barrier System Features, Events, and Processes and Degradation Modes Analysis.* ANL-EBS-MD-000035 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000217.0216.

6.2.2 Fault Movement Shears Waste Container 1.2.02.03.00

Description: Fault slip could partially or completely offset one or more tunnels in the repository thereby shearing any waste containers that lie across the fault plane.

Screening Decision: Exclude

Screening Decision Basis: Low Probability

Screening Argument: This FEP is addressed in the Disruptive Events PMR and Disruptive Events FEPs AMR (CRWMS M&O 2000f) and excluded based on low probability.

TSPA Disposition: Exclude from the TSPA as described under the Screening Argument.

Relevant AMRs: CRWMS M&O 2000e. *Effects of Fault Displacement on Emplacement Drifts*. ANL-EBS-GE-000004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000228.0529.

CRWMS M&O 2000f. *Disruptive Events FEPS*. ANL-WIS-MD-000005 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0017.

6.2.3 Seismic Vibration Causes Container Failure 1.2.03.02.00

FEP Description: Seismic activity causes repeated vibration of the container and/or container-rock wall contact, damaging the container and its contents.

Screening Decision: Exclude (To Be Verified (TBV), pending additional data and/or analysis).

Screening Decision Basis: Low consequence based on the design requirements of waste package and drip shield. The screening decision and basis are subject to verification pending additional waste package and drip shield design requirement analysis (TBV).

Screening Argument: This FEP was originally directed at vertical emplacement of containers in boreholes. The current design (Enhanced Design Alternative II) is to place large containers horizontally in the drifts with drip shield and backfill over the drip shield (CRWMS M&O 1999b, Design Constraint 2.2.1.1.9). This design removes the possibility of container-rock wall contact due to seismic activity. In addition, preliminary analyses (CRWMS M&O 2000a) indicate that even under most severe seismic vibration, the waste package (WP) will not undergo failure. For the drip shield (DS), no analyses have been performed to date on the effects of seismic vibration on mechanical damage/failure of drip shield. The Emplacement Drift System design criteria require that the drip shield be designed to withstand a Category 2 design basis earthquake without rupturing or parting between individual drip shield units and without contacting waste packages (CRWMS M&O 2000aa, System Design Criteria 1.2.1.16 and 1.2.1.17).

This FEP is also addressed in the Disruptive Events PMR and Disruptive Events FEPs AMR (CRWMS M&O 2000f) and was excluded (TBV) for the waste package and included for the drip shield.

TSPA Disposition: Exclude from the TSPA as described under the Screening Argument.

Relevant AMRs: CRWMS M&O 2000c. *Engineered Barrier System Features, Events, and Processes and Degradation Modes Analysis.* ANL-EBS-MD-000035 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000217.0216.

CRWMS M&O 2000e. *Effects of Fault Displacement on Emplacement Drifts.* ANL-EBS-GE-000004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000228.0529.

CRWMS M&O 2000f. *Disruptive Events FEPS.* ANL-WIS-MD-000005 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0017.

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

CRWMS M&O 2000u. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0208.

IRSR Issues: Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem.

6.2.4 Magma Interacts with Waste 1.2.04.04.00

FEP Description: An igneous intrusion in the form occurs through the repository, intersecting waste. This leads to accelerated waste container failure (e.g., attack by magmatic volatiles, damage by fragmented magma, thermal effects) and dissolution of waste (CSNF (Commercial Spent Nuclear Fuel), DSNF (Defense Spent Nuclear Fuel), DHLW (Defense High Level Waste)).

Screening Decision: Include

Screening Decision Basis: N/A

Screening Argument: Include in the TSPA as described under TSPA Disposition.

TSPA Disposition: Magma interactions with the waste are included in the TSPA as part of disruptive events analyses. This FEP is addressed in the Disruptive Events FEPs screening document (CRWMS M&O 2000f).

Relevant AMRs: CRWMS M&O 2000f. *Disruptive Events FEPS.* ANL-WIS-MD-000005 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0017.

CRWMS M&O 2000v. *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada.* ANL-MGR-GS-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0215.

6.2.5 Corrosion of Waste Containers 2.1.03.01.00

FEP Description: Corrosion may contribute to waste package failure. Corrosion is most likely to occur at locations where water drips on the waste packages, but other mechanisms should be considered.

Screening Decision: Include

Screening Decision Basis: N/A

Screening Argument: Included in TSPA as described under TSPA Disposition.

TSPA Disposition: Corrosion is the most likely process leading to degradation and failure of waste containers and drip shields in the repository. All significant corrosion modes are included in waste container/drip shield corrosion modeling. These include dry-air oxidation, humid-air corrosion, and aqueous corrosion processes such as general corrosion, localized (pitting and crevice) corrosion, stress corrosion cracking, hydrogen induced corrosion, and microbial influenced corrosion.

Corrosion is included in TSPA as part of waste package degradation analyses. Waste container/drip shield corrosion is modeled with the Waste Package Degradation computer code (WAPDEG) (CRWMS M&O 1999a, 1999h). WAPDEG produces waste package/drip shield degradation profiles consisting of the fraction of waste packages/drip shields failed versus time and the average (per failed waste package/drip shield) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model.

Relevant AMRs:

CRWMS M&O 1999g. *Abstraction of Models for Stainless Steel Structural Material Degradation.* ANL-EBS-PA-000005 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0264.

CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*. ANL-EBS-MD-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000202.0172.

CRWMS M&O 2000h. *General Corrosion and Localized Corrosion of the Drip Shield.* ANL-EBS-MD-000004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1185.

CRWMS M&O 2000i. *Calculation of General Corrosion Rate of Drip Shield and Waste Package Outer Barrier to Support WAPDEG Analysis*. CAL-EBS-PA-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000319.0047.

CRWMS M&O 2000l. *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier.* ANL-EBS-MD-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000328.0590.

CRWMS M&O 2000m. *Aging and Phase Stability of Waste Package Outer Barrier.* ANL-EBS-MD-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000410.0407.

CRWMS M&O 2000n. *Abstraction of Models For Pitting And Crevice Corrosion Of Drip Shield And Waste Package Outer Barrier*. ANL-EBS-PA-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0262.

CRWMS M&O 2000o. *Abstraction of Models For Stress Corrosion Cracking Of Drip Shield and Waste Package Outer Barrier And Hydrogen Induced Cracking Of Drip Shield*. ANL-EBS-PA-000004 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0261.

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

CRWMS M&O 2000q. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier and the Stainless Steel Structural Material*. ANL-EBS-MD-000005 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0259.

CRWMS M&O 2000r. *Hydrogen Induced Cracking of Drip Shield.* ANL-EBS-MD-000006 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1179.

CRWMS M&O 2000s. *Degradation of Stainless Steel Structural Material.* ANL-EBS-MD-000007 REV 00. Las Vegas, Nevada: CRWMS M&O. MOL.20000329.1188.

CRWMS M&O 2000x. *Analysis Of Mechanisms For Early Waste Package Failure*. ANL-EBS-MD-000023 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL. 20000223.0878.

IRSR Issues: Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers.

6.2.6 Stress Corrosion Cracking of Waste Containers 2.1.03.02.00

FEP Description: Waste packages become wet at specific locations that are stressed. Stress-corrosion cracking ensues. The possibility of stress corrosion cracking under dry conditions or due to thermal stresses should also be addressed as part of this FEP.

Screening Decision: Include for waste container.
Exclude for drip shield.

Screening Decision Basis: Low consequence.

Screening Argument: Included in TSPA for the waste container, as described under TSPA Disposition. All fabrication welds of the drip shield will be fully annealed before placed in the emplacement drift, and thus are not subject to SCC. Also, the major sources of stresses in the drip shield induced by backfill and earthquakes are not significant for SCC (CRWMS M&O 2000q, Section 5, Assumption 1). Additionally, even if it occurs, the SCC cracks in the drip shield, which are likely “tight” openings and filled with corrosion products and/or other precipitates, is not expected to compromise significantly the intended function of the drip shield (i.e., preventing the dripping water from contacting the waste package).

TSPA Disposition: Stress corrosion cracking (SCC) is one of a number of corrosion mechanisms that could potentially lead to eventual compromise of waste containers and/or drip shields. SCC is included in TSPA as part of waste package degradation analysis but is excluded in the analysis of drip shield degradation.

Waste container SCC is modeled with the Waste Package Degradation (WAPDEG) computer code (CRWMS M&O 1999a, 1999h). WAPDEG produces waste package/drip shield degradation profiles consisting of the fraction of waste packages/drip shields failed versus time and the average (per failed waste package/drip shield) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model (see FEP 2.1.03.01.00).

Because, among other exposure condition parameters, tensile stress is required to initiate SCC, and the waste container closure welds are the only places with such tensile stresses, only the waste container closure welds are considered for SCC (CRWMS M&O 2000q). The other fabrication welds of the waste container will be fully annealed before waste is loaded into the waste containers, and thus are not subject to SCC.

Presence of stable "liquid" water is required to initiate corrosion processes (including SCC) that are supported by electrochemical corrosion reactions. A threshold relative humidity is used in the waste package degradation analysis to simulate such a corrosion initiation condition. The threshold relative humidity is based on the deliquescence point of $NaNO_3$ salt (CRWMS M&O 2000b, 2000l). Therefore, under conditions with the relative humidity below the threshold value (i.e., dry conditions), SCC will not occur.

Thermally induced stresses are addressed in Section 6.2.11 (Mechanical Impact on Waste Container) and Section 6.2.24 (Differing Thermal Expansion of Repository Components).

Relevant AMRs:

CRWMS M&O 2000m. *Aging and Phase Stability of Waste Package Outer Barrier.* ANL-EBS-MD-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000410.0407.

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

CRWMS M&O 2000q. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier and the Stainless Steel Structural Material.* ANL-EBS-MD-000005 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0259.

CRWMS M&O 2000r. *Hydrogen Induced Cracking of Drip Shield.* ANL-EBS-MD-000006 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1179.

IRSR Issues: Subissue 1: The Effects of Corrosion Processes on the Lifetime of the containers

6.2.7 Pitting of Waste Containers 2.1.03.03.00

FEP Description: Localized corrosion in pits leads to failure of the waste package.

Screening Decision: Include

Screening Decision Basis: N/A

Screening Argument: Included in TSPA as described under TSPA Disposition.

TSPA Disposition: Localized (pitting and crevice) corrosion is one of a number of corrosion mechanisms that potentially lead to eventual compromise of waste containers and/or drip shields in the repository.

As discussed in detail in the companion abstraction AMR, localized corrosion of waste container outer barrier (Alloy 22) and drip shield is not likely to occur under repository-relevant exposure conditions (CRWMS M&O 2000n). Localized corrosion initiation and propagation models are included in TSPA as part of waste package degradation analysis. Waste container localized corrosion is modeled with the Waste Package Degradation (WAPDEG) computer code (CRWMS M&O 1999a, 1999h). WAPDEG produces waste package degradation profiles consisting of the fraction of waste packages failed versus time and the average (per waste package) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model (see FEP 2.1.03.01.00).

Relevant AMRs: CRWMS M&O 1999g. *Abstraction of Models for Stainless Steel Structural Material Degradation.* ANL-EBS-PA-000005 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0264.

CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*. ANL-EBS-MD-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000202.0172.

CRWMS M&O 2000h. *General Corrosion and Localized Corrosion of the Drip Shield.* ANL-EBS-MD-000004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1185.

CRWMS M&O 2000n. *Abstraction of Models For Pitting And Crevice Corrosion Of Drip Shield And Waste Package Outer Barrier*. ANL-EBS-PA-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0262.

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

IRSR Issues: Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers.

6.2.8 Hydride Cracking of Waste Containers 2.1.03.04.00

FEP Description: A potential failure mechanism for containers (and drip shields) involves the uptake of hydrogen and the formation of metal hydrides, which may mechanically weaken the container and promote corrosion.

Screening Decision: Exclude for drip shield.
Exclude for waste container (TBV, pending additional data and/or analysis).

Screening Decision Basis: Low Consequence for drip shield.

Low probability for waste package outer barrier.

Screening Argument: Hydrogen generated at cathodic site of corroding metal can migrate into the metal and form hydride phases within the metal components. This could make the metal to be more brittle and degrade its mechanical properties. The hydride phases cause the metal to be more susceptible to cracking and to localized corrosion. The extent of the hydride phases is determined by the amount of hydrogen uptake by the metal.

Hydrogen induced cracking (HIC) of drip shield is a potential degradation mechanism that could cause catastrophic failure of drip shield if the hydrogen uptake in the titanium drip shield is greater than the critical hydrogen concentration (CRWMS M&O 2000r). In the current design of backfill placed over the drip shield, crevice corrosion and passive general corrosion of the drip shield are two feasible processes in the repository that could lead HIC failure of the drip shield. Hydrogen is produced as a result of the corrosion processes, and some of the produced hydrogen can be absorbed by the titanium metal. The absorbed hydrogen then diffuses into the metal forming the hydrides in the metal. Because the drip shield will not be subject to crevice corrosion under the exposure conditions anticipated in the repository (CRWMS M&O 2000n), general corrosion is the only mechanism that could cause HIC in the drip shield. Results of the bounding analyses have shown that the time that the hydrogen uptake concentration reaches the critical hydrogen concentration under the exposure conditions anticipated in the repository (CRWMS M&O 2000r) is greater than the time required to initiate the drip shield breach by general corrosion (about 20,000 years) (CRWMS M&O 2000w, Section 3.2.5). Therefore, HIC is not a limiting degradation process that could affect the drip shield performance in the repository, and is excluded based on low consequence.

HIC of the waste container outer barrier (Alloy 22) is not considered to be a possible degradation mechanism under repository-relevant exposure conditions. Handbook data (ASM International 1987, pp. 650-651) indicate that fully annealed nickel-base alloys such as Alloy 22 may be immune to hydrogen-induced embrittlement (hydride cracking) (CRWMS M&O 2000a). The susceptibility to hydride cracking may be enhanced only when the strength level of this alloy is increased either by cold working or by aging at a temperature of 540°C at which ordering and/or grain-boundary segregation can occur. The susceptibility to cracking will be reduced with decreasing strength level and correspondingly with increasing aging temperature. However, since the waste package temperature will be sufficiently less than 540°C, the possibility of HIC in Alloy 22 will be very remote (CRWMS M&O 2000a). Therefore, this FEP for the waste package outer barrier is excluded on the basis of low probability.

TSPA Disposition: Exclude from TSPA as described under the Screening Argument.

Relevant AMRs: CRWMS M&O 2000r. *Hydrogen Induced Cracking of Drip Shield.* ANL-EBS-MD-000006 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1179.

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

IRSR-Issues: Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers.

6.2.9 Microbially-Mediated Corrosion of Waste Container 2.1.03.05.00

FEP Description: Microbial activity may catalyze corrosion by otherwise kinetically hindered oxidizing agents. The most likely process is microbial reduction of groundwater sulfates to sulfides and reaction of iron with dissolved sulfides.

Screening Decision: Include for waste container /

Exclude for drip shield (TBV pending additional data and/or analysis).

Screening Decision Basis: N/A for waste container.

Low Consequence for drip shield.

Screening Argument: Quantitative data on microbiologically-induced-corrosion (MIC) of drip shield materials such as titanium (Ti) Grades 7 and 16 are not available from the literature. It is considered that the candidate titanium alloy is immune to MIC (CRWMS M&O 2000a). The MIC is excluded for the drip shield (Ti- Grade 7) corrosion modeling in the upstream process model analysis (CRWMS M&O 2000h). Therefore, this FEP is excluded for drip shield based on low consequence (TBV pending additional data and/or analysis).

TSPA Disposition: Microbiologically influenced corrosion (MIC) is included in TSPA as part of waste package degradation analysis. Waste container microbiologically influenced corrosion is modeled with the Waste Package Degradation (WAPDEG) computer code (CRWMS M&O 1999a, 1999h). WAPDEG produces waste package degradation profiles consisting of the fraction of waste packages failed versus time and the average (per waste package) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model (see FEP 2.1.03.01.00).

The potential effect of MIC on waste container corrosion is analyzed with an enhancement factor approach, assuming MIC increases corrosion penetration rate. In this approach, the abiotic corrosion rate is multiplied by the enhancement factor when the exposure conditions in the emplacement drift warrant significant microbial activity (CRWMS M&O 2000b).

Relevant AMRs: CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*. ANL-EBS-MD-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000202.0172.

CRWMS M&O 2000h. *General Corrosion and Localized Corrosion of the Drip Shield.* ANL-EBS-MD-000004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1185.

CRWMS M&O 2000j. *In Drift Microbial Communities.* ANL-EBS-MD-000038 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000331.0661.

CRWMS M&O 2000s. *Degradation of Stainless Steel Structural Material.* ANL-EBS-MD-000007 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1188.

IRSR-Issues: Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers.

6.2.10 Internal Corrosion of Waste Container 2.1.03.06.00

FEP Description: Aggressive chemical conditions within the waste package could contribute to corrosion from the inside out. Effects of different waste forms, including CSNF and DSNF, are considered in this FEP.

Screening Decision: Exclude (TBV pending additional data and/or analysis).

Screening Decision Basis: Low Consequence

Screening Argument: The waste container could be corrosively attacked from inside if corrosive condition exists in the inside. After being loaded with waste, the waste containers are to be filled with the inert gas (helium) prior to the closure, displacing water and oxygen inside the container (DOE 1998, Section 5.1.2.1). The helium gas-filled condition will provide an inert environment inside the container, and will maintain the environment for insignificantly low corrosion rates. Prior to the breach of the containers, there should be no or minimum corrosion because of the inert environment inside the container.

Analyses referenced in *Features, Events, and Processes Resolution Responses* (CRWMS M&O 2000a) suggest that the most likely cause of any possible internal corrosion is the residual moisture remaining in the waste package at the time of emplacement. The potential source of this moisture is believed to be primarily waterlogged failed fuel rods. Analyses have indicated that the amount of moisture available to cause internal corrosion is very limited and even with very conservative assumptions, the potential for degradation of the container materials is very remote (CRWMS M&O 2000a).

Defense spent nuclear fuel (DSNF) canisters containing N-reactor spent fuel (MCOs) may have significant quantities of residual free and chemically bound water at the time of sealing prior to interim storage (CRWMS M&O 2000a). However, the N-reactor spent fuel cladding is significantly damaged, thus exposing chemically reactive uranium metal surface which would scavenge this residual water producing uranium oxide and uranium hydride. Other forms of DSNF are relatively less damaged, and will contain much lower quantities of residual water due to drying prior to sealing for interim storage. Damaged DSNF, other than N-reactor spent fuel will be placed in high integrity canisters that will contain any residual water indefinitely (CRWMS M&O 2000a).

The HLW glass-containing canisters are constrained by the canister filling process and the associated waste acceptance preliminary specification (WAPS) requirements of having very little residual water content to prevent corrosion damage of the waste container internal surfaces (CRWMS M&O 2000a).

The commercial spent nuclear fuel (CNSF) assemblies will be dried prior to their insertion into the waste packages (WPs). Since the internal basket structure of these WPs has sufficient internal surfaces of carbon steel, the insignificant amount of remaining residual water will be scavenged by carbon steel. Thus, the potential for corrosion damage to the container internal surfaces is very low (CRWMS M&O 2000a).

In view of above rationale, this FEP is excluded based on low consequence.

TSPA Disposition: Exclude from TSPA as described under the Screening Argument.

Relevant AMRs: N/A

6.2.11 Mechanical Impact on Waste Container 2.1.03.07.00

FEP Description: Mechanical impact on the waste container is caused by internal and external forces such as internal gas pressure, forces caused by swelling corrosion products, rock fall, ground motion during seismic events, and possible waste package movement.

Screening Decision: Exclude mechanical damage of the waste container and drip shield by rock fall.

Exclude mechanical damage of the waste container and drip shield by ground motion during seismic events (TBV pending additional data and/or analysis).

Exclude mechanical damage by internal gas pressure and swelling corrosion products.

Screening Decision Basis: Low consequence for mechanical damage of the waste container and drip shield by rock fall.

Low consequence for mechanical damage of the waste container and drip shield by ground motion during seismic events (TBV).

Low Consequence for mechanical damage by internal gas pressure and swelling corrosion products.

Screening Argument: Mechanical damage of the waste container and drip shield by rockfall is discussed in greater detail under FEP 2.1.07.01.00 – Rockfall (large block). This FEP discussion also provides relevant references discussing the issue in a great detail. In addition, the Emplacement Drift System design criteria require that the drip shield be designed to withstand a 13 metric tons rock falling onto the top of the backfill without rupturing the drip shield or parting between individual drip shield units and without contacting waste packages (CRWMS M&O 2000aa, System Design Criteria 1.2.1.14 and 1.2.1.15). In view of the above rationale, this FEP is excluded based on low consequence.

Mechanical damage of the waste container and drip shield by ground motion during seismic events is discussed in greater detail under FEP 1.2.03.02.00 – Seismic Vibration Causes Waste Container and Drip Shield Failure. In addition, the Emplacement Drift System design criteria require that the drip shield be designed to withstand a Category 2 design basis earthquake without rupturing or parting between individual drip shield units and without contacting waste packages (CRWMS M&O 2000aa, System Design Criteria 1.2.1.16 and 1.2.1.17). In view of the above rationale, this FEP is excluded as low consequence (TBV pending additional data and/or analysis).

A calculation of the maximum stresses developed in the waste package due to internal pressurization as a result of fuel rod rupture at 400°C is less than the ASME code requirements for the allowable tensile strength (CRWMS M&O 1999f). Therefore, with the current robust waste container design, the pressurization of the internal gas under the expected repository condition would not cause mechanical damage to the waste container In general, corrosion products have greater volume than the bare metal. When the corrosion products form in a tightly confined space, the volume increase by the corrosion products generates swelling pressure to the surrounding and thus could cause mechanical damage to the surrounding. In the current design of waste package and engineered barrier system in the emplacement drift (Enhanced Design Alternative II, CRWMS M&O 1999b), there is no possibility of forming such a tightly confined space such that the swelling corrosion products could cause mechanical damage to the Alloy 22 outer barrier. Therefore, mechanical damages by internal gas pressure and swelling corrosion products are excluded based on low consequence.

TSPA Disposition: Exclude from TSPA as described under the Screening Argument.

Relevant AMRs: CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

CRWMS M&O 2000u. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0208.

IRSR Issues: Subissue 2: The Effects of Phase Instability and Initial Defects on the Mechanical Failure and Lifetime of the Containers.

6.2.12 Juvenile and Early Failure of Waste Containers 2.1.03.08.00

FEP Description: Waste packages and drip shields may fail prematurely because of manufacturing defects, improper sealing, or other factors related to quality control during manufacture and emplacement of the waste packages and drip shields.

Screening Decision: Include manufacturing and welding defects in waste container degradation analysis.

Exclude manufacturing defects in drip shield degradation analysis.

Exclude early failure of waste container and drip shield from improper quality control during the emplacement.

Screening Decision Basis: N/A for manufacturing and welding defects in waste container failure.

Low consequence for manufacturing defects in drip shield failure.

Low probability for potential early failure of waste container and drip shield from improper quality control during the emplacement.

Screening Argument: The major effect of pre-existing manufacturing defects is to provide sites for crack growth by stress corrosion cracking (SCC), potentially leading to a premature failure. Among other exposure condition parameters, tensile stress is required to initiate SCC (CRWMS M&O 2000q). Because all the fabrication welds in drip shields will be fully annealed before placement in the emplacement drift, drip shields are not subject to SCC (CRWMS M&O 2000q). Also, other sources of stresses in the drip shield induced by backfill and earthquakes are insignificant to SCC (CRWMS M&O 2000q, Section 5, Assumption 1). Thus manufacturing defects in drip shield are excluded from TSPA analysis based on low consequence.

After emplacement the waste containers and drip shields will be inspected. If there is any damage, they would be retrieved (CRWMS M&O 1998). Thus, the probability of having potential early failure of waste container and drip shield from improper quality control during the emplacement will be extremely small and is excluded from the TSPA analysis based on low probability.

TSPA Disposition: Effect of manufacturing and welding defects on waste container failure is addressed by including the defect flaws in stress corrosion cracking (SCC) analysis (CRWMS M&O 2000q). As discussed in Section 6.2.6 (FEP2.1.03.02.00), only the closure welds are considered for SCC. Accordingly, the defects in the closure welds will be considered in TSPA analysis through the SCC analysis.

Relevant AMRs: CRWMS M&O 2000o. *Abstraction of Models For Stress Corrosion Cracking Of Drip Shield and Waste Package Outer Barrier And Hydrogen Induced Cracking Of Drip Shield*. ANL-EBS-PA-000004 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0261.

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

CRWMS M&O 2000q. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier and the Stainless Steel Structural Material*. ANL-EBS-MD-000005 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0259.

CRWMS M&O 2000x. *Analysis Of Mechanisms For Early Waste Package Failure*. ANL-EBS-MD-000023 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19991101.0207.

IRSR Issues: Subissue 2: The Effects of Phase Instability and Initial Defects on the Mechanical Failure and Lifetime of the Containers.

6.2.13 Copper Corrosion 2.1.03.09.00

FEP Description: Chemical reactions involving copper corrosion have been identified as being of potential interest for repository programs considering the use of copper containers.

Screening Decision: Exclude.

Screening Decision Basis: Low Probability.

Screening Argument: Copper is not considered for use as an engineered barrier at Yucca Mountain, and thus this FEP is not considered relevant for the Yucca Mountain TSPA. There will be zero probability to have a copper waste container in the repository. Therefore, copper corrosion is excluded based on low probability.

TSPA Disposition: Exclude from the TSPA as described under the Screening Argument.

6.2.14 Container Healing 2.1.03.10.00

FEP Description: Pits and holes in waste packages could be partially or fully plugged by chemical or physical reactions during or after their formation, affecting corrosion processes and water flow and radionuclide transport through the breached container. Passivation by corrosion products is a potential mechanism for container healing.

Screening Decision: Exclude

Screening Decision Basis: Low Consequence

Screening Argument: Plugging (or healing) of corrosion holes or pits in waste container by corrosion products and mineral precipitates is a potentially possible process in the repository. However, there are large uncertainties associated with the quantification of the effect of the process on water flow and radionuclide transport through the openings. Because of this, potential performance credit from the plugging (or healing) of the corrosion penetration openings are not taken into account in TSPA analysis. Therefore, this FEP is excluded based on low consequence.

TSPA Disposition: Exclude from the TSPA as described under the Screening Argument.

Relevant AMRs: CRWMS M&O 1999e. *In Drift Corrosion Products.* ANL-EBS-MD-000041 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000106.0438.

CRWMS M&O 2000u. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0208.

6.2.15 Container Form 2.1.03.11.00

FEP Description: The specific forms of the various waste packages and internal waste containers that are proposed for the Yucca Mountain repository can affect long-term performance. Waste package form may affect container strength through the shape and dimensions of the container and affect heat dissipation through container volume and surface area. Waste package materials may affect physical and chemical behavior of the disposal area environment. Waste package integrity will affect the releases of radionuclides from the disposal system. Waste packages may have both local effects and repository scale effects. All types of waste packages and containers, including CSNF, DSNF, and DHLW, should be considered.

Screening Decision: Exclude

Screening Decision Basis: Low consequence.

Screening Argument: The waste package/drip shield/repository design has been standardized for the Yucca Mountain Project (CRWMS M&O 1999b). While there is more than one waste package design expected to be used in the proposed repository, they are all similar in their design, the fabrication methodology used, and their dimensions (CRWMS M&O 2000k, p. 1). Therefore, there will be little variation in strength, dimensions, and shape of the waste packages used in the proposed repository. Effects of different waste forms (CSNF, DSNF, and DHLW) on heat dissipation and physical and chemical conditions in the vicinity the waste packages are indirectly included in the TSPA analysis through different thermal-hydrologic-geochemical responses and their impacts on corrosion processes. Waste package and drip shield degradation modes are modeled with the Waste Package Degradation computer code (WAPDEG) (CRWMS M&O 1999a,1999h). The WAPDEG code makes use of several different

	thermal-hydrologic-geochemical “time histories” during a given simulation which encompass the variability in exposure conditions due to “container form.”
TSPA Disposition:	Exclude from the TSPA as described under the Screening Argument.
Relevant AMRs:	CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044. CRWMS M&O 2000g. *Abstraction of Drift Scale Coupled Processes.* ANL-NBS-HS-000029 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0032. CRWMS M&O 2000z. *Abstraction of Near Field Environment Drift Thermodynamic Environment and Percolation Flux.* ANL-EBS-HS-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0039. CRWMS M&O 2000y. *Physical and Chemical Environmental Abstraction Model.* ANL-EBS-MD-000046 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0043.

6.2.16 Container Failure (Long-Term) 2.1.03.12.00

FEP Description:	Waste packages and drip shields have a potential to fail over long periods of times by a variety of mechanisms, including general corrosion, stress corrosion cracking, pit corrosion, hydride cracking, microbially-mediated corrosion, internal corrosion, and mechanical impacts.
Screening Decision:	Include
Screening Decision Basis:	N/A
Screening Argument:	Include in the TSPA as described under TSPA Disposition.
TSPA Disposition:	Long-term corrosion degradation and failure of waste containers and drip shields in the repository are included in TSPA as part of waste package degradation analyses. The analyses accounts for the major degradation mechanisms and processes that are likely in the repository. The waste container and drip shield corrosion are modeled with the Waste Package Degradation computer code (WAPDEG) (CRWMS M&O 1999a, 1999h). WAPDEG produces waste package degradation profiles consisting of the fraction of waste packages/drip shields failed versus time and the average (per

failed waste package/drip shield) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model.

Relevant AMRs: CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

IRSR-Issues: Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers.

6.2.17 Effects and Degradation of Drip Shield 2.1.06.06.00

FEP Description: The drip shield will affect the amount of water reaching the waste package. Behavior of the drip shield in response to rockfall, ground motion, and physical, chemical degradation processes should be considered. Effects of the drip shield on the disposal region environment (for example, changes in relative humidity and temperature below the shield) should be considered for both intact and degraded conditions. Degradation processes specific to the chosen material should be identified and considered. For example, oxygen embrittlement should be considered for titanium drip shields.

Screening Decision: Exclude damage to drip shield by rock fall.

Exclude damage to drip shield by ground motion during seismic events (TBV pending additional data and/or analysis).

Include physical and chemical degradation processes.

Screening Decision Basis: Low consequence for rockfall.

Low consequence for ground motion (TBV pending additional data and/or analysis).

Screening Argument: Mechanical damage of the drip shield by rockfall is discussed in greater detail under FEP 2.1.07.01.00 – Rockfall (large block). This FEP discussion also provides relevant references discussing the issue in detail. In addition, the Emplacement Drift System design criteria require that the drip shield be designed to withstand a 13 metric tons rock falling onto the top of the backfill without rupturing the drip shield or parting between individual drip shield units and without contacting waste packages (CRWMS M&O 2000aa, System Design Criteria 1.2.1.14 and 1.2.1.15). In view of the above rationale, this FEP is excluded based on low consequence.

Mechanical damage of the drip shield by ground motion during seismic events is discussed in greater detail under FEP 1.2.03.02.00 – Seismic Vibration Causes Waste Container and Drip Shield Failure. In addition, the Emplacement Drift System design criteria require that the drip shield be designed to withstand a Category 2 design basis earthquake without rupturing the drip shield or parting between individual drip shield units and without contacting waste packages (CRWMS M&O 2000aa, System Design Criteria 1.2.1.16 and 1.2.1.17). In view of the above rationale, this FEP is excluded as low consequence (TBV pending additional data and/or analysis).

TSPA Disposition: Physical and chemical degradation processes for the drip shield are included in TSPA as part of waste package and drip shield degradation analyses. The analyses accounts for the major degradation mechanisms and processes that are likely in the repository (CRWMS M&O 2000p). This includes corrosion-induced and other degradation and failure processes.

The waste container and drip shield degradation are modeled with the Waste Package Degradation computer code (WAPDEG) (CRWMS M&O 1999a, 1999h). WAPDEG produces waste package and drip shield degradation profiles consisting of the fraction of waste packages/drip shields failed versus time and the average (per failed waste package/drip shield) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model. In addition, the model is designed to accounts for the effect on the drip shield of non-corrosion degradation processes such as rockfall or seismic motion. These effects are considered for both the intact and degraded states of the drip shield.

Relevant AMRs: CRWMS M&O 1999e. *In Drift Corrosion Products.* ANL-EBS-MD-000041 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000106.0438.

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

CRWMS M&O 2000u. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0208.

CRWMS M&O 2000y. *Physical and Chemical Environmental Abstraction Model*. ANL-EBS-MD-000046 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0043.

IRSR Issues: Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem.

6.2.18 Effects at Material Interfaces 2.1.06.07.00

FEP Description: Physical and chemical effects that occur at the interfaces between materials in the drift, such as at the contact between the backfill and the drip shield, may affect the performance of the system.

Screening Decision: Include

Screening Decision Basis: N/A

Screening Argument: Include in the TSPA as described under TSPA Disposition.

TSPA Disposition: Waste container and drip shield corrosion degradation analysis includes the effects of material interfaces in the repository. The thermal-hydrologic-geochemical condition analyses in the repository include effects of materials present in the emplacement drift, including waste package, drip shield and backfill. The corrosion degradation analysis includes effect on corrosion processes of backfill gravel contacting the drip shield and waste container (CRWMS M&O 2000p).

Relevant AMRs: CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*. ANL-EBS-MD-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000202.0172.

CRWMS M&O 2000h. *General Corrosion and Localized Corrosion of the Drip Shield*. ANL-EBS-MD-000004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1185.

CRWMS M&O 2000l. *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier*. ANL-EBS-MD-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000328.0590.

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation*. ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

CRWMS M&O 2000u. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0208.

CRWMS M&O 2000y. *Physical and Chemical Environmental Abstraction Model.* ANL-EBS-MD-000046 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0043.

IRSR Issues: Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem.

6.2.19 Rockfall (Large Block) 2.1.07.01.00

FEP Description: Rockfalls occur large enough to mechanically tear or rupture waste packages and drip shields.

Screening Decision: Exclude

Screening Decision Basis: Low Consequence

Screening Argument: This FEP is addressed in the Disruptive Events PMR and Disruptive Events FEPs AMR (CRWMS M&O 2000f) and excluded based on low consequence. The Emplacement Drift System design criteria require that the drip shield be designed to withstand a 13 metric tons rock falling onto the top of the backfill without rupturing the drip shield or parting between individual drip shield units and without contacting waste packages (CRWMS M&O 2000aa, System Design Criteria 1.2.1.14 and 1.2.1.15). In view of the above rationale, this FEP is excluded based on low consequence.

TSPA Disposition: Exclude from the TSPA as described under the Screening Argument.

Relevant AMRs: CRWMS M&O 2000c. *Engineered Barrier System Features, Events, and Processes and Degradation Modes Analysis.* ANL-EBS-MD-000035 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000217.0216.

CRWMS M&O 2000d. *Drift Degradation Analysis.* ANL-EBS-MD-000027 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000107.0328.

CRWMS M&O 2000f. *Disruptive Events FEPS.* ANL-WIS-MD-000005 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0017.

IRSR Issues: Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem.

6.2.20 Creeping of Metallic Materials in the EBS 2.1.07.05.00

FEP Description: Metals used in the waste package or drip shield may deform by creep processes in response to deviatoric stress.

Screening Decision: Exclude (TBV pending additional inputs and/or analysis from Waste Package Design).

Screening Decision Basis: Low Consequence

Screening Argument: Creep data were not found for Alloy 22 (ASTM B 575 N06022) or Titanium Grade 7, but the composition of Alloy 22 is very similar to that of Alloy 625 (ASTM B 443). Creep data for Alloy 625 are reported only for temperatures of 1200°F (650°C) and higher (Haynes International 1993, p. 5). This temperature is well above the expected temperatures for repository operations. At the repository temperatures, the rate of creep is expected to be very low, because the stresses required to cause creep are not present (CRWMS M&O 2000a).

TSPA Disposition: Exclude from the TSPA as described under the Screening Argument.

Relevant AMRs: N/A

6.2.21 Volume Increase of Corrosion Products 2.1.09.03.00

FEP Description: Corrosion products have a higher molar volume than the uncorroded material. Increases in volume during corrosion will change the stress state in the material being corroded.

Screening Decision: Exclude.

Screening Decision Basis: Low Consequence.

Screening Argument: For the waste package and EBS emplacement design considered at the repository (Enhanced Design Alternative II II, CRWMS M&O 1999b), the volume increase by corrosion products from the corroding materials in the emplacement drift is not expected to affect the stress state of drip shields or waste containers, or other EBS materials in the drift. Therefore, this FEP is excluded based on low consequence.

FEP 2.1.03.07.00 - Mechanical Impact on the Waste Container and Drip Shield also deals with corrosion products, namely, the internal and external forces caused by swelling. This portion of the FEP is also excluded.

TSPA Disposition: Exclude from the TSPA as described under the Screening Argument.

Relevant AMRs: N/A

6.2.22 Electrochemical Effects in Waste and EBS 2.1.09.09.00

FEP Description: Electrochemical effects may establish an electric potential within the drift or between materials in the drift and more distant metallic materials. Migration of ions within such an electric field could affect corrosion of metals in the EBS and waste, and could also have a direct effect on the transport of radionuclides as charged ions.

Screening Decision: Exclude (TBV pending additional data and/or analysis).

Screening Decision Basis: Low Consequence.

Screening Argument: Electrochemical reactions between the materials in the emplacement drift could establish an electrical field within the drift. Both the Titanium Grade 7 used for the drip shield and Alloy 22 for the waste-container outer barrier are highly corrosion resistant. Thus significant perturbations to the electrochemical system in the drift are required to increase corrosion potential of the materials and to affect their corrosion behaviors (CRWMS M&O 2000b, 2000h). In the current design of the engineered barrier system in the emplacement drift (Enhanced Design Alternative II, CRWMS M&O 1999b), the potential electrical fields that could be set up in the drift is not expected to be large enough to induce unexpected corrosion behaviors of the drip shield or the waste-container outer barrier. Therefore, this FEP is excluded on the basis of low consequence (TBV pending additional data and/or analysis).

TSPA Disposition: Exclude from the TSPA as described under the Screening Argument.

Relevant AMRs: CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*. ANL-EBS-MD-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000202.0172.

CRWMS M&O 2000h. *General Corrosion and Localized Corrosion of the Drip Shield.* ANL-EBS-MD-000004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1185.

IRSR Issues: Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem.

6.2.23 Biological Activity in Waste and EBS 2.1.10.01.00

FEP Description: Biological activity in the waste and engineered barrier system (EBS) may affect disposal-system performance by altering degradation processes such as corrosion of the waste packages and waste form (including cladding), by affecting radionuclide transport through the formation of colloids and biofilms, and by generating gases.

Screening Decision: Include for waste container.

Exclude for drip shield (TBV pending additional data and/or analysis).

Screening Decision Basis: N/A for waste container.

Low Consequence for drip shield.

Screening Argument: Quantitative data on microbiologically-induced-corrosion (MIC) of drip shield materials such as titanium (Ti) Grades 7 and 16 are not available from the literature. It is considered that the candidate titanium alloy is immune to MIC (CRWMS M&O 2000a). The MIC is excluded for the drip shield (Ti- Grade 7) corrosion modeling in the upstream process model analysis (CRWMS M&O 2000h). Therefore, this FEP is excluded for drip shield based on low consequence (TBV pending additional data and/or analysis).

TSPA Disposition: Microbes can influence the initiation and rate of waste container corrosion. Alloy 22 (waste container outer barrier material) could be subject to microbiologically influenced corrosion (MIC) depending on the microbial activity in the repository. MIC is included in TSPA as part of waste package degradation analysis. Waste container microbiologically influenced corrosion is modeled with the Waste Package Degradation (WAPDEG) computer code (CRWMS M&O 1999a, 1999h). WAPDEG produces waste package degradation profiles consisting of the fraction of waste packages failed versus time and the average (per waste package) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model (see FEP 2.1.03.01.00).

The potential effect of MIC on waste container corrosion is analyzed with an enhancement factor approach, assuming MIC increases corrosion penetration rate. In this approach, the abiotic corrosion rate is multiplied by the enhancement factor when the exposure conditions in the emplacement drift warrant significant microbial activity (CRWMS M&O 2000b).

Relevant AMRs: CRWMS M&O 2000y. *Physical and Chemical Environmental Abstraction Model.* ANL-EBS-MD-000046 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0043.

CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier.* ANL-EBS-MD-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000202.0172.

CRWMS M&O 2000h. *General Corrosion and Localized Corrosion of the Drip Shield.* ANL-EBS-MD-000004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1185.

CRWMS M&O 2000j. *In Drift Microbial Communities.* ANL-EBS-MD-000038 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000331.0661.

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

IRSR Issues: Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers.

6.2.24 Differing Thermal Expansion of Repository Components 2.1.11.05.00

FEP Description: Thermally-induced stresses could alter the performance of the waste or EBS. For example, thermal stresses could create pathways for preferential fluid flow in the backfill or through the drip shield.

Screening Decision: Exclude (TBV pending additional inputs and/or analysis from Waste Package Design).

Screening Decision Basis: Low Consequence. The screening decision and basis are subject to verification pending additional waste package and drip shield design requirement analysis (TBV).

Screening Argument: The current drift design minimizes the thermal gradient and temperatures where differential expansion occurs (due to differences in component/rock properties) will not be reached.

To mitigate any possibility of thermal stresses as a result of differing thermal expansion coefficients of the waste package materials, the waste package barriers will be constructed with a gap up to 4 mm between the outer barrier (Alloy 22) and inner barrier (316 NG stainless steel) (CRWMS M&O 2000a). Therefore, this FEP is excluded based on low consequence (TBV pending additional data and/or analysis).

TSPA Disposition: Exclude from TSPA analysis as described under the Screening Argument.

Relevant AMRs: CRWMS M&O 2000c. *Engineered Barrier System Features, Events, and Processes and Degradation Modes Analysis.* ANL-EBS-MD-000035 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000217.0216.

CRWMS M&O 2000d. *Drift Degradation Analysis.* ANL-EBS-MD-000027 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000107.0328.

6.2.25 Thermal Sensitization of Waste Containers Increases Fragility 2.1.11.06.00

FEP Description: Phase changes in waste package materials can result from long-term storage at moderately hot temperatures in the repository. Stress-corrosion cracking, intergranular corrosion, or mechanical degradation may ensue.

Screening Decision: Include.

Screening Decision Basis: N/A

Screening Argument: Include in the TSPA as described under TSPA Disposition.

TSPA Disposition: Alloy 22 is known to be subject to “aging” and phase instability when exposed to elevated temperatures. The processes involve precipitation of different secondary phases and restructuring of the microstructure. The affected material exhibits increased brittleness and decreased resistance to corrosion, especially to localized corrosion and stress corrosion cracking (SCC) (CRWMS M&O 2000m). Preliminary testing results have shown that the waste container outer barrier (Alloy 22) could be subject to aging and phase instability under repository thermal conditions (CRWMS M&O 2000m). A quantitative assessment of these effects is currently uncertain.

Effects of potential thermal sensitization of the waste package outer barrier (such as thermally induced stress-corrosion cracking, intergranular corrosion, or mechanical degradation) are included in TSPA as part of waste package degradation analysis. The effects are accounted for with a corrosion enhancement factor that is applied to the corrosion rate for the non-affected condition (CRWMS M&O 2000b). The waste container thermally induced corrosion mechanisms are modeled with the Waste Package Degradation (WAPDEG) computer code (CRWMS M&O 1999a, 1999h). WAPDEG produces waste package degradation profiles consisting of the fraction of waste packages failed versus time and the average (per waste package) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model (see FEP 2.1.03.01.00).

Relevant AMRs: CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*. ANL-EBS-MD-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000202.0172.

CRWMS M&O 2000m. *Aging and Phase Stability of Waste Package Outer Barrier*. ANL-EBS-MD-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000410.0407.

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation*. ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

IRSR Issues: Subissue 1: The Effects of Corrosion Processes on the Lifetime of the containers.

6.2.26 Gas Generation (H_2) from Metal Corrosion 2.1.12.03.00

FEP Description: Gas generation can affect the mechanical behavior of the host rock and engineered barriers, chemical conditions, and fluid flow, and, as a result, the transport of radionuclides. Gas generation due to oxic corrosion of waste containers, cladding, structural materials will occur at early times following closure of the repository. Anoxic corrosion may follow the oxic phase, if all oxygen is depleted. The formation of a gas phase due to the thermal heating in the repository will produce steam around the canister which will exclude oxygen from the iron, thus inhibiting further corrosion for a limited amount of time in the early period of the repository.

Screening Decision: Exclude (TBV pending additional data and/or analysis).

Screening Decision Basis: Low Consequence.

Screening Argument: A repository in the UZ in the Yucca Mountain repository is expected to be connected to the atmosphere and to be operating under oxidizing conditions. Therefore any gases generated by metal corrosion would escape from the drifts. Hydrogen (H_2) gas could be generated from the reduction of water as a result of corrosion reactions underway (more likely under reducing conditions). This hydrogen gas generation would be less likely under oxidizing conditions that are assumed for the repository. Furthermore, the hydrogen gas generation rate, if occur, would be very low for the current repository design (Enhanced Design Alternative II, CRWMS M&O 1999b) because of very low corrosion rates of Alloy 22 (waste container outer barrier) and titanium Grade 7 (drip shield). Alloy 22 and titanium Grade 7 were selected because of their excellent resistance to pitting and crevice corrosion and stress corrosion cracking. Additionally Alloy 22 is very low in iron so the issue of iron corrosion is not relevant to the current design. For the waste package materials, the hydrogen that may be produced from their corrosion in the repository is expected to be small (TBV pending additional data and/or analysis). Therefore, this FEP is excluded based on low consequence.

This FEP is also addressed in the Engineered Barrier System (EBS) PMR and EBS FEPs AMR (CRWMS M&O 2000c) and also excluded based on low consequence.

TSPA Disposition: Exclude from the TSPA as described under the Screening Argument.

Relevant AMRs: CRWMS M&O 2000r. *Hydrogen Induced Cracking of Drip Shield.* ANL-EBS-MD-000006 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1179.

CRWMS M&O 2000t. *In-Drift Gas Flux & Composition.* ANL-EBS-MD-000040 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0195.

CRWMS M&O 2000y. *Physical and Chemical Environmental Abstraction Model.* ANL-EBS-MD-000046 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0043.

6.2.27 Radiolysis 2.1.13.01.00

FEP Description: Alpha, beta, gamma and neutron irradiation of water can cause disassociation of molecules, leading to gas production and changes in chemical conditions (Eh, pH, concentration of reactive radicals).

Screening Decision: Exclude.

Screening Decision Basis: Low Consequence.

Screening Argument: When significant radiation field and stable "liquid" water exist on the surface of waste container and drip shield, radiolysis of water and some dissolved species in the water could produce highly oxidizing and corrosive fluids. Only radiolysis due to gamma and neutron radiation is possible as long as the container is intact. Alpha and beta radiolysis will be of importance after canister failure, when water gets in close contact with the fuel matrix.

Electrochemical testing results simulating the radiation exposure conditions that are expected in the repository have shown that the amount of the corrosion potential increase of Alloy 22 (waste container outer barrier) and Titanium Grade 7 (drip shield) from the radiolysis should not affect their localized corrosion behavior (CRWMS M&O 2000b, 2000h). Therefore, the radiolysis effect on waste-container outer barrier and drip shield is excluded in TSPA analysis based on low consequence.

TSPA Disposition: Exclude from the TSPA as described under the Screening Argument.

Relevant AMRs: CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*. ANL-EBS-MD-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000202.0172.

CRWMS M&O 2000h. *General Corrosion and Localized Corrosion of the Drip Shield.* ANL-EBS-MD-000004 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1185.

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. Submit to RPC URN-0044.

IRSR Issues: Subissue 1: The Effects of Corrosion Processes on the Lifetime of the containers.

6.2.28 Radiation Damage in Waste and EBS 2.1.13.02.00

FEP Description: Strong radiation fields could lead to radiation damage to the waste forms and containers (CSNF, DSNF, DHLW), backfill, drip shield, seals and surrounding rock.

Screening Decision: Exclude (TBV pending additional data and/or analysis).

Screening Decision Basis: Low Consequence.

Screening Argument: The dose rate of gamma radiation at the surface of the waste package and drip shield is determined by the concentration of the various radioactive isotopes within the waste package (as functions of age, type, and length of time the fuel was in the reactor etc.) and the attenuation provided by the engineered barriers (ASM International 1987, pp. 971-974) (CRWMS M&O 2000a). However, the type and dose rates of radiation emitted from decaying wastes are not sufficient to degrade the metallurgical and mechanical properties of the waste package and drip shield materials, and their protective/passive layers (CRWMS M&O 2000a). The only significant effect of radiation will be the change in external environment due to groundwater radiolysis (ASM International 1987, pp. 971-974). Therefore, this FEP is excluded due to low consequence compared to waste container and drip shield corrosion (TBV pending additional data and/or analysis concerning radiation embrittlement of waste package and drip shield materials).

TSPA Disposition: Exclude from the TSPA as described under the Screening Argument.

Relevant AMRs: N/A

7. CONCLUSIONS

The analyses documented in this AMR are for the Enhanced Design Alternative II (EDA II) design (CRWMS M&O 1999b). In this design, a drip shield is placed over the waste package with backfill emplaced over the drip shield (see Design Constraint 2.2.1.1.9 of CRWMS M&O 1999b). The current FEPs analysis results in this AMR are not applicable to a no-backfill design. Twenty-eight (28) FEPs relevant to waste package and drip shield degradation processes have been screened and are summarized in Table 3. This table shows the FEP number, FEP name, screening decision (include/exclude) and basis for “Exclude” decision.

Table 3. Summary of Waste Package FEPs.

FEP Number	FEP Name	Screening Decision	Screening Basis
1.1.03.01.00	Error in waste or backfill emplacement	Exclude	Low probability
1.2.02.03.00	Fault movement shears waste container	Exclude	Low probability
1.2.03.02.00	Seismic vibration causes container failure	Exclude	Low consequence (TBV)
1.2.04.04.00	Magma interacts with waste	Include	
2.1.03.01.00	Corrosion of waste containers	Include	
2.1.03.02.00	Stress corrosion cracking of waste containers	Include WP/Exclude DS	Low consequence
2.1.03.03.00	Pitting of waste containers	Include	
2.1.03.04.00	Hydride cracking of waste containers	Exclude DS/Exclude WP	Low consequence DS/Low probability WP (TBV)
2.1.03.05.00	Microbially-mediated corrosion of waste container	Include WP/ Exclude DS	Low consequence (TBV)
2.1.03.06.00	Internal corrosion of waste container	Exclude	Low consequence (TBV)
2.1.03.07.00	Mechanical impact of waste container	Exclude	Low consequence (TBV)
2.1.03.08.00	Juvenile and early failure of waste containers	Include WP/ Exclude DS/Exclude WP & DS	Low consequence/Low probability
2.1.03.09.00	Copper corrosion	Exclude	Low probability
2.1.03.10.00	Container healing	Exclude	Low consequence
2.1.03.11.00	Container form	Exclude	Low consequence
2.1.03.12.00	Container failure (long term)	Include	
2.1.06.06.00	Effects and degradation of drip shield	Exclude/Exclude/Include	Low consequence/Low consequence (TBV)
2.1.06.07.00	Effects at material interfaces	Include	
2.1.07.01.00	Rockfall (large block)	Exclude	Low consequence
2.1.07.05.00	Creeping of metallic materials in the EBS	Exclude	Low consequence (TBV)
2.1.09.03.00	Volume increase of corrosion products	Exclude	Low consequence
2.1.09.09.00	Electrochemical effects in waste and EBS	Exclude	Low consequence (TBV)
2.1.10.01.00	Biological activity in waste and EBS	Include WP/ Exclude DS	Low consequence (TBV)
2.1.11.05.00	Differing thermal expansion of repository components	Exclude	Low consequence (TBV)
2.1.11.06.00	Thermal sensitization of waste containers increases fragility	Include	
2.1.12.03.00	Gas generation (H_2) from metal corrosion	Exclude	Low consequence (TBV)
2.1.13.01.00	Radiolysis	Exclude	Low consequence
2.1.13.02.00	Radiation damage in waste and EBS	Exclude	Low consequence (TBV)

The technical information used in this AMR as input has been obtained, where possible, from controlled source documents and references using the appropriate document identifiers or records system accession numbers. In some cases, the technical information strongly supports an exclude decision for a particular FEP but is not sufficiently rigorous to support the low probability or low consequence criteria (see 4.2 for details of these criteria). In these instances the Screening Decision has been labelled “To Be Verified (TBV) pending additional data and/or analysis”. The TBV designation will be carried in the FEPs data base until it is resolved.

In addition to FEPs screening, this analysis addresses the Nuclear Regulatory Commission (NRC) Issue Resolution Status Report (IRSR) for Container Life and Source Term Key Technical Issue (CLST KTI) for container life and source term (NRC, 1999).

This document and its conclusions may be affected by technical product input information that requires confirmation. Any changes to the document or its conclusions that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the Document Input Reference System database.

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8.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

None.

9. ATTACHMENTS

No Attachment.